Diablo Canyon - San Simeon Earthquake Meeting

May 27, 2004, Rockville, MD

Introduction

- Decision not to shut down was appropriate
- San Simeon excursion from DE vertical response spectra at top of containment was to be expected
- DCPP DE licensing/design basis provides adequate margin for OBE function
- San Simeon earthquake was consistent with the tectonic framework developed in the LTSP

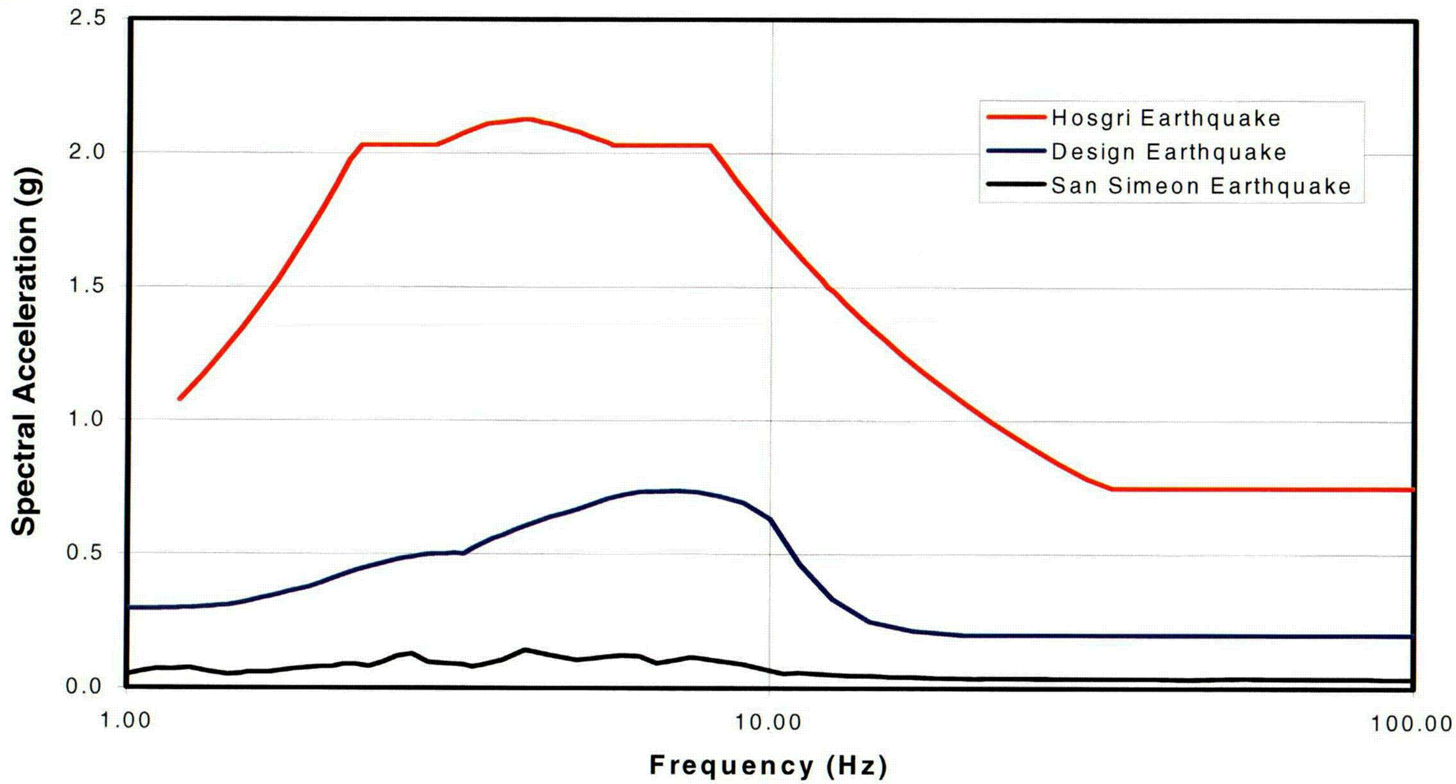
Why DCPP Did Not Shutdown on December 22, 2003

- Maximum ground acceleration (<0.05g) less than DE value of 0.2g
- All plant systems continued to operate
- Plant inspection (walkdown per CP M-4) did not identify any damage or system leakage

Subsequent Evaluation of No Shutdown Decision

The San Simeon Earthquake was significantly less than the Design Earthquake and did not have the potential to cause damage to DCPP

San Simeon Free Field Response Spectra less than DE



Free Field Ground Motion - Plant North-South Direction

OBE Exceedance Check per RG 1.166

- The OBE is exceeded only when both of the following ground motion parameters are exceeded for one of the three directional components:
  - Response Spectrum Check
  - Damage Potential Check

OBE Exceedance Check per RG 1.166 (cont.)

- Response Spectrum Check
  - Computed response spectrum for the recorded free field ground motion less than the OBE spectrum for frequencies $\leq$ 10 Hz.

$$\frac{San\ Simeon\ Earthquake}{Design\ Earthquake} = 0.35 \leq 1.0$$

  - Therefore, there was no OBE exceedance.

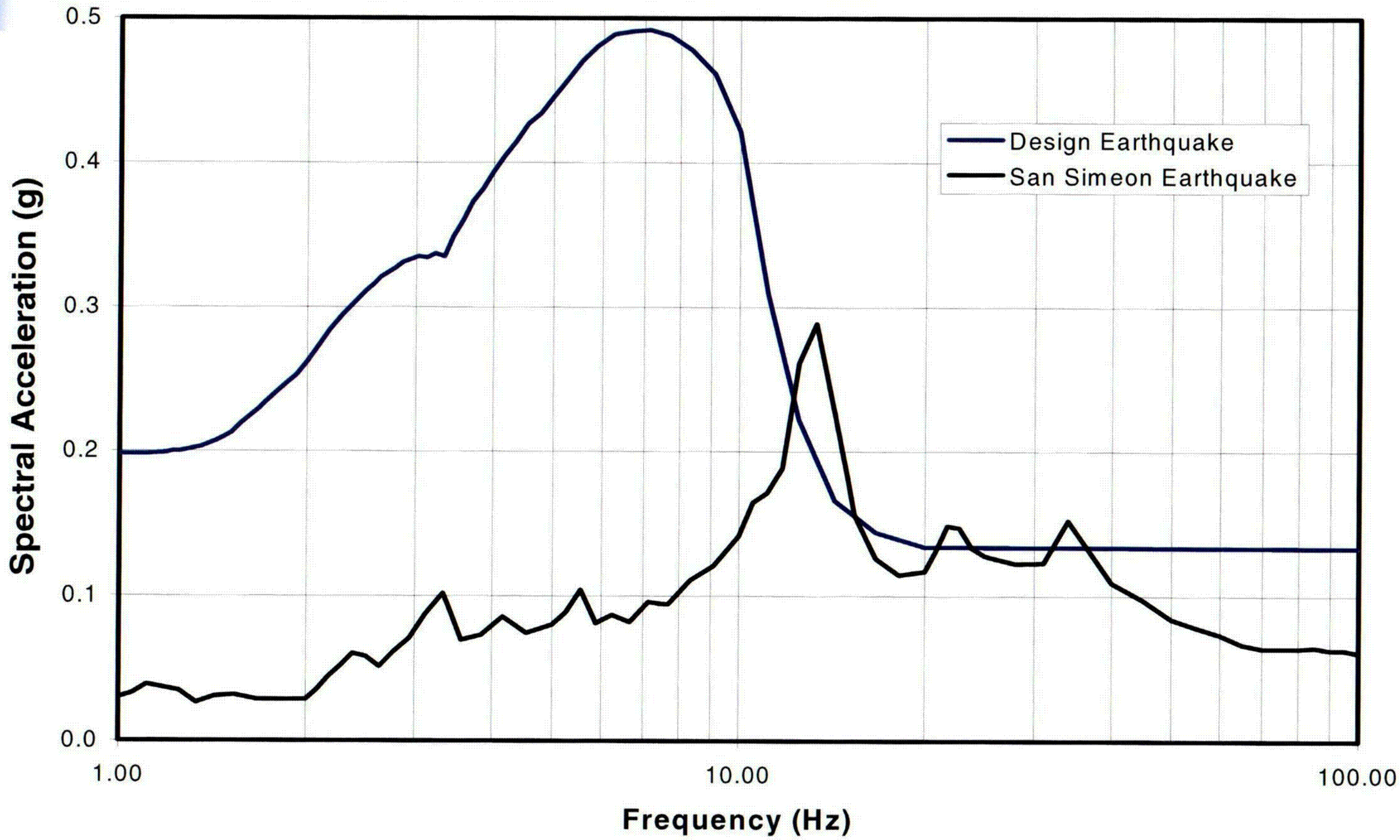
OBE Exceedance Check per RG 1.166 (cont.)

- Damage Potential Check
  - Cumulative absolute velocity (CAV) less than 0.16 g-sec.

$$\frac{San\ \ Simeon\ \ \ Earthquake}{RG\ \ 1.166\ \ \ Limit} = 0.51 \leq 1.0$$

  - Therefore, there was no OBE exceedance.

DE Response Spectra Excursion at Top of Containment (TOC)

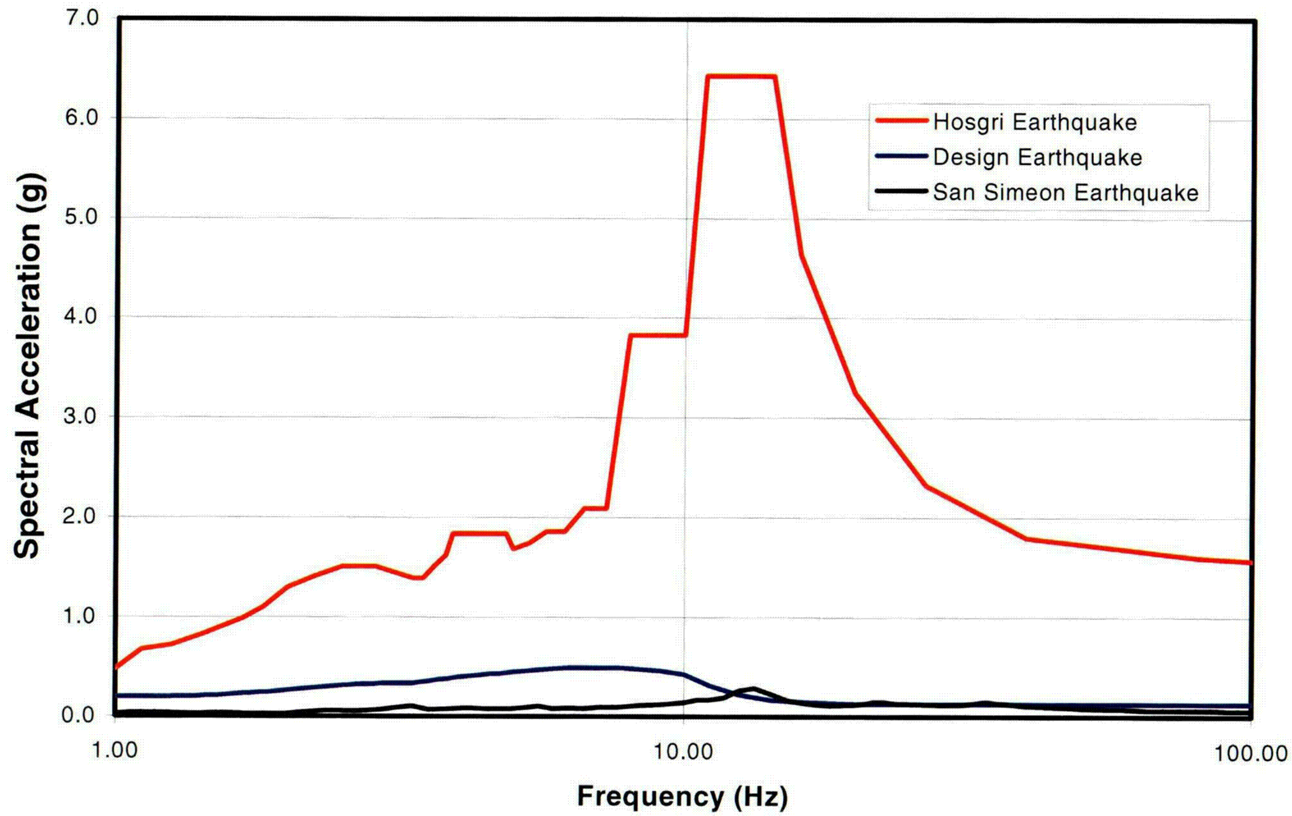


Top of Containment - Vertical Direction

DE Response Spectra Excursion at TOC (cont.)

- DE spectra excursion at the top of the containment resulted from two factors:
  - Large structures were considered to be rigid vertically, consistent with industry practice at the time. Thus, vertical amplification was not considered in the DE analyses.
  - Top of Containment acted as a diaphragm to amplify vertical motion (with a resonant frequency of approx. 13 Hz). Vertical amplification <u>was</u> considered in the HE and LTSP analyses.

DE Vertical Response Spectra Compared to HE at TOC



Top of Containment - Vertical Direction

Conclusion of DE Vertical Response Spectra Excursion-TOC

- Vertical peak frequency matched HE, as expected, confirming models used for HE and LTSP analyses
- Amplitude of vertical acceleration was very low relative to HE
- HE design ensures the protection of public health and safety

Seismic Licensing/Design History

- Plant designed to DE/DDE (late '60s)
  - DE = 0.2g; DDE = 0.4g
  - DE(vertical) = 2/3 x DE (horizontal) static
  - No vertical amplification
- SC I SSCs were re-analyzed to Hosgri spectra (late '70s)
  - HE spectra include vertical amplification
  - Significant field modifications made

Seismic Licensing/Design History (cont.)

- Independent Design Verification Program re-analyzed all SC I SSCs (1982-1984)
  - Updated models for key SC I structures
  - Additional field modifications made
- Long Term Seismic Program (1985-1991)
  - Served as a useful check on the adequacy of the seismic margins
  - Commitment to continue to evaluate new seismic information with respect to impact on DCPP

Purpose of Engineering Study

- Validate the adequacy of the DE/DDE seismic design of safety related structures, systems and components, considering amplified vertical ground motion

Study DE Differences from Licensing Basis DE

- Vertical Amplification
- RG 1.61 Damping
- Frequency up to 33 Hz

Engineering Study – Overall Scope

- Structures
- Systems
  - Piping
  - Electrical Raceways
  - HVAC Ducts
- Components

Engineering Study Scope Selection

- SSCs in rigid areas (no amplification)
  - Reactor
  - Reactor coolant pumps
  - Steam generators
  - Items supported by crane wall
  - Containment cylinder below 140′
  - ESF pump rooms (including AFW)

Engineering Study Scope Selection (cont.)

- SSCs on grade (no amplification)
  - Diesel generators
  - ASW pumps/piping
  - CCW heat exchangers
  - Emergency water tanks

Engineering Study Scope Selection (cont.)

- SSCs on flexible slabs, but shake table tested
  - 480v switchgear
  - Batteries/inverters
  - 4kv switchgear
  - Cable spreading room equipment
  - Control room equipment

Engineering Study Scope Selection (cont.)

- Top of Containment – Studied
- 140' Auxiliary Bldg - Studied
  - slabs 5 and 11

Engineering Study Scope - Equipment

- Electrical
  - Battery chargers, vital MCCs, 4kV switchgear, relays, fuses, etc.
- Instruments & Controls
  - Switches, transmitters, mechanical panels, main control boards, air regulators, cabinets, etc.
- Mechanical
  - Pumps/motors, heat exchangers, containment fan coolers, etc.
- HVAC
  - Fans/motors, thermostats, condensers, etc.

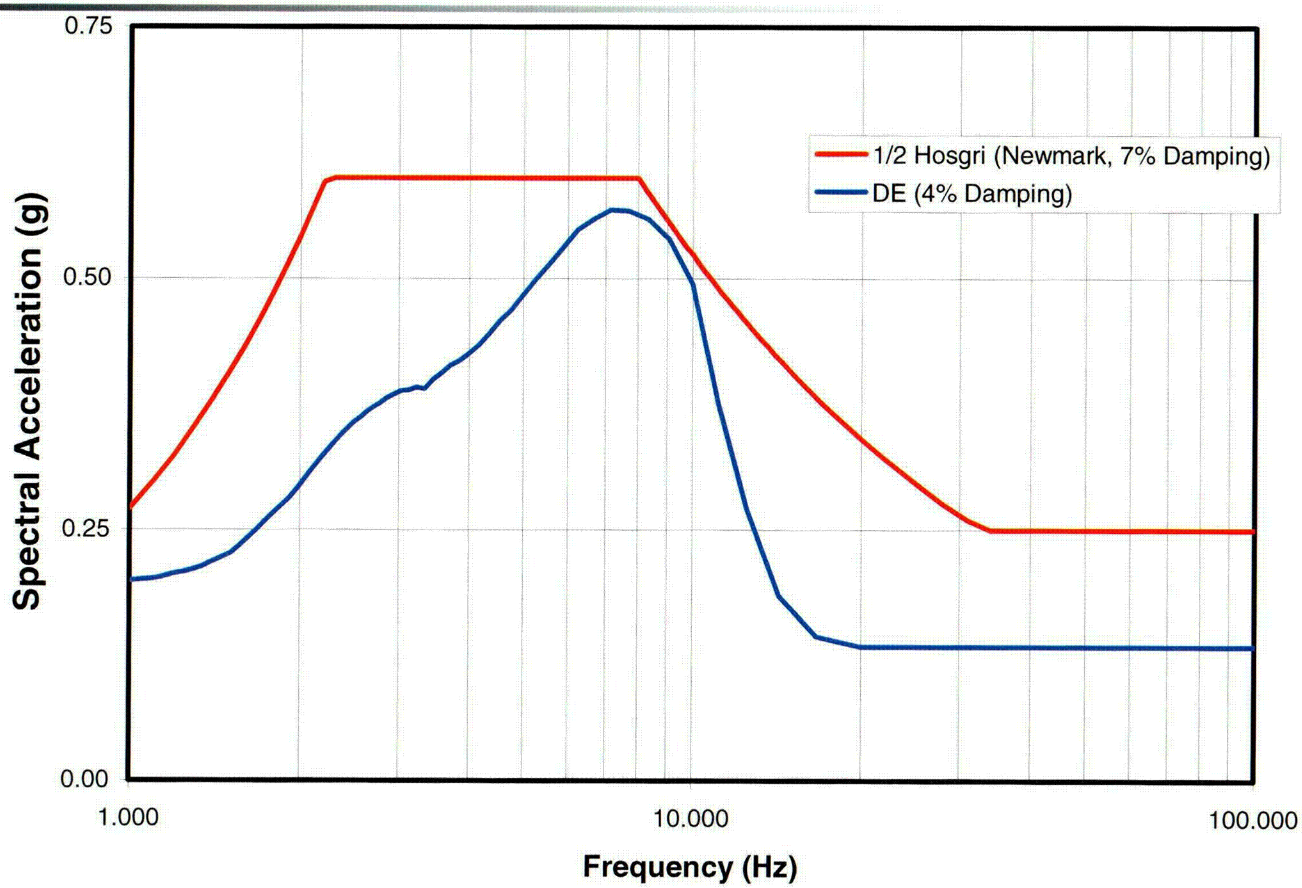
Engineering Study Assumptions/ Methodologies - Equipment

- Equipment qualification for DCPP was done by:
  - Shake table testing,
  - Analysis, or
  - Shake table testing and Analysis

Engineering Study Assumptions/ Methodologies – Equipment Qualified by Shake Table Testing

- To meet OBE provisions of IEEE-344, equipment was tested/qualified to 50%-66% of the HE
  - NSSS components by Westinghouse
  - Balance of Plant (BOP) by PG&E
- To meet SSE provisions of IEEE-344, equipment tested/qualified to HE

Engineering Study Assumptions/ Methodologies – Equipment Qualified by Shake Table Testing (cont.)



Free Field Input Response Spectra - Vertical Direction

C04

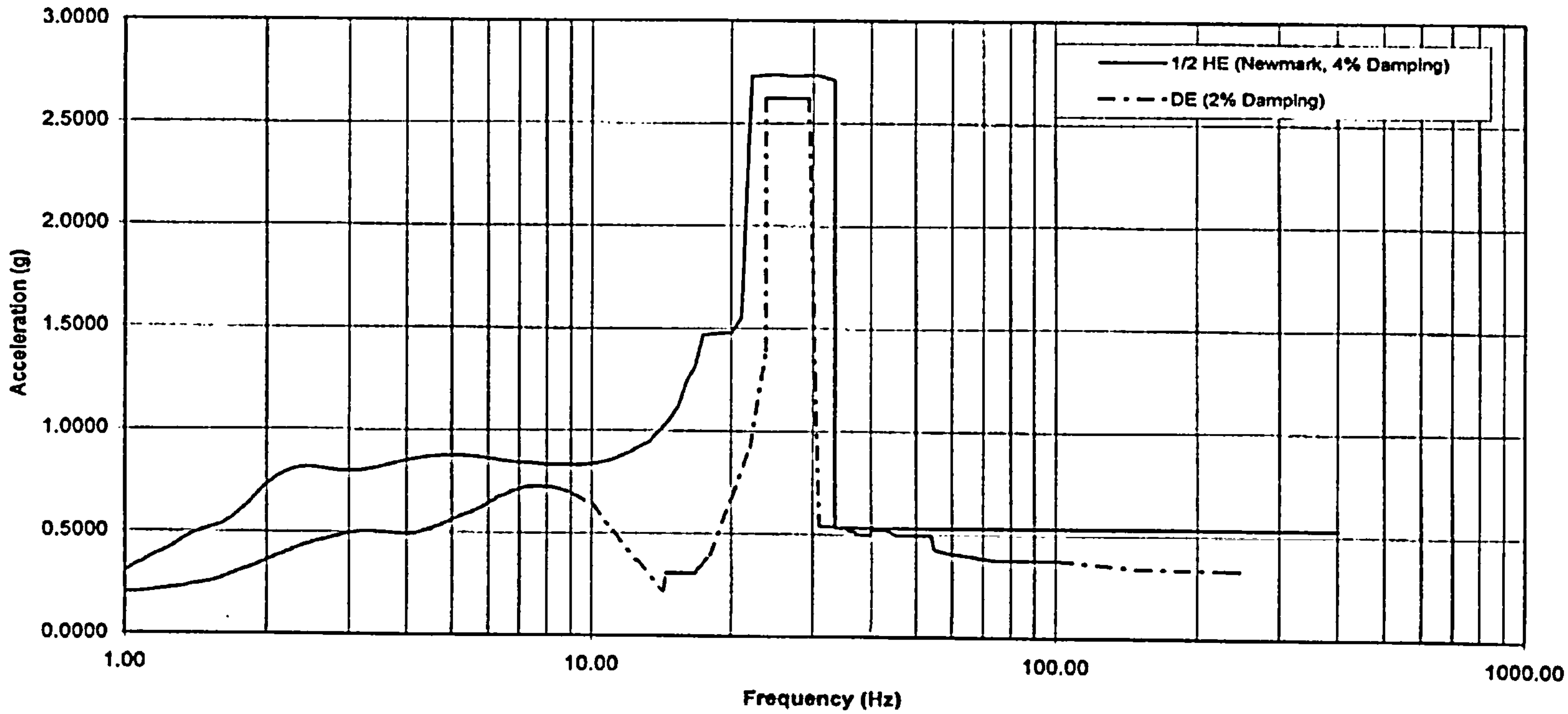
Engineering Study Assumptions/ Methodologies – Equipment Qualified by Analysis

- Evaluation for Slabs 5 & 11
  - Evaluated for HE
  - Compared demand vertical amplified spectra at 2% damping (for DE equipment) with HE vertical (4% damping)
  - Compared allowable stress for HE vs. DE to identify the governing case

Engineering Study Assumptions/ Methodologies – Equipment Qualified by Analysis (cont.)

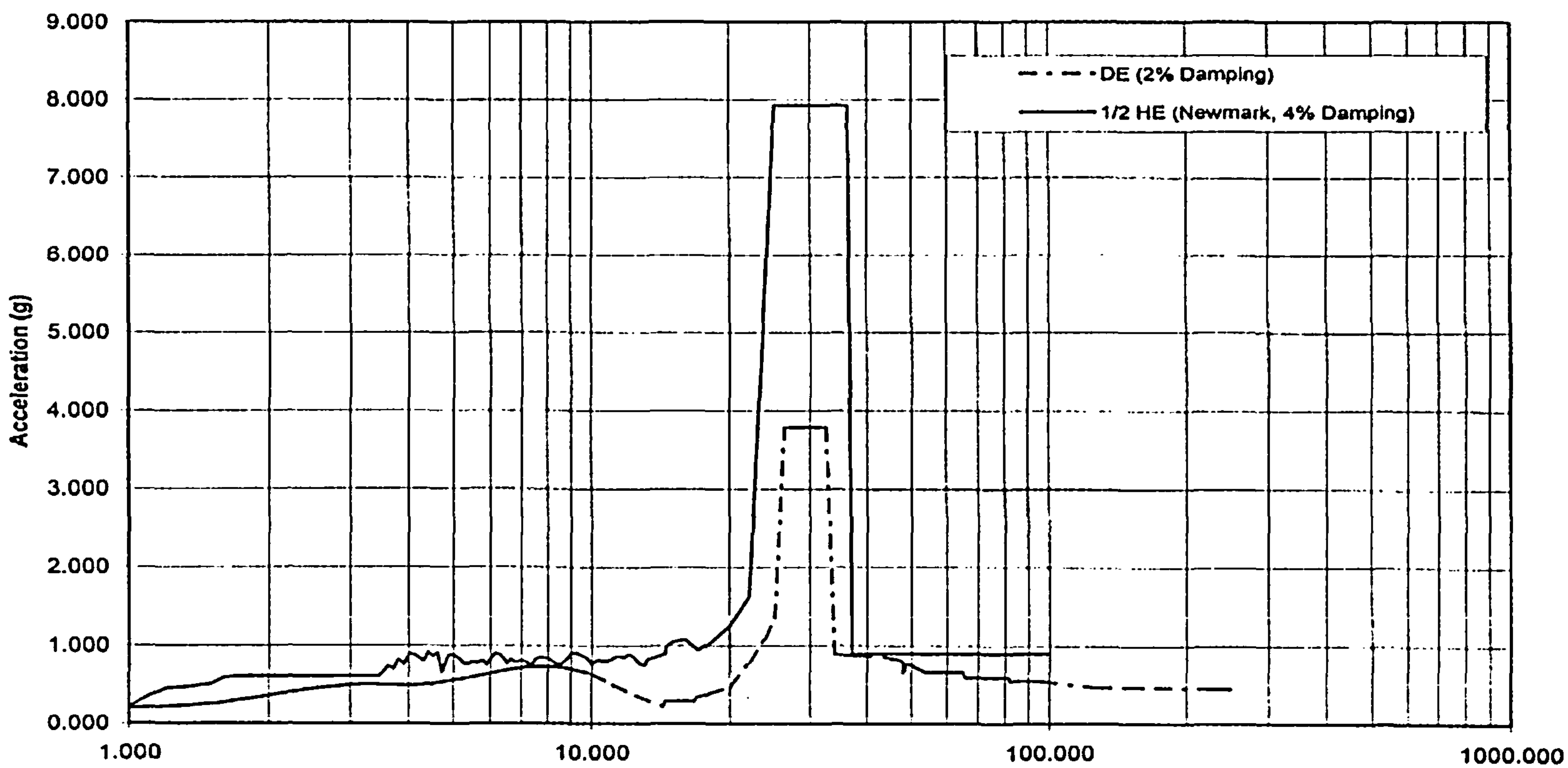
Comparison of Slab 11 Node 85 Vertical Spectra

1/2 Hosgri Earthquake vs. Amplified Design Earthquake



Engineering Study Assumptions/ Methodologies – Equipment Qualified by Analysis (cont.)

Comparison of Slab 5 Node 200 Vertical Spectra
1/2 Hosgri Earthquake vs. Amplified Design Earthquake



Engineering Study Results – Equipment Qualified by Analysis

- The HE vertical demand load (spectra) governs over study DE
  - The vertical seismic spectra for HE is $\geq$ 2 x Study DE (amplified vertical spectra)
  - The HE stress allowables are $\leq$ 2 x DE stress allowables
- Based on the review of approximately 40 calculations, it was judged that amplified vertical DE would not have an adverse impact on the conclusions of the calculation, primarily due to significantly higher HE loads as well as high horizontal loads

Engineering Study Conclusions – Equipment

- Shake table tested equipment is qualified for DE with vertical amplification
- Vertical component of seismic is a relatively small portion of the demand load on equipment and is not a governing case for qualification by analysis

Engineering Study Scope – Piping Systems

- Analyses for 5 piping systems rigidly connected to structures addressed in study
  - Two Containment Spray header piping systems connected to the containment dome structure
  - Two analyses in Auxiliary Building connected to "Slab 11" (Elev. 140 ft.)
  - One analysis in Auxiliary Building connected to "Slab 5" (Elev. 140 ft.)

Engineering Study Assumptions/ Methodologies – Piping Systems

- The piping stress analysis study used the following parameters:

Piping	Study	Licensing Basis
DE Vertical Damping	1 %	0.5 %
DDE Vertical Damping	2 %	0.5 %
DE / DDE Horizontal Damping	0.5 %	0.5 %
DE / DDE Modal Freq. Cut off	33 Hz.	20 Hz.

Engineering Study Results – Piping Systems

Analysis #	Seismic Case	Existing (Licensing) (psi)	Study (psi)	Allowable (psi)	Study Stress Ratio
2-112 (Slab 11)	DE	13676	13680	18000	0.76
	DDE	21965	21903	27000	0.81
8-118 (Slab 11)	DE	14861	14977	22320	0.67
	DDE	22413	22496	33480	0.67
8-301 (Slab 5)	DE	6112	9569	22440	0.43
	DDE	10824	10969	33660	0.33
5-106 (Ct. Dome)	DE	17518	17988	22320	0.81
	DDE	32675	24774	33480	0.74
5-107 (Ct. Dome)	DE	16085	16552	22320	0.74
	DDE	30310	24806	33480	0.74

Engineering Study Conclusions – Piping Systems

- The piping stresses remained well within the DE/DDE code design allowables for the study case (with vertical DE/DDE spectra modified to include amplification)
- Pipe support loads remained within design allowables

Engineering Study Scope - Structures

- Containment Structure (Exterior Shell)
- Auxiliary Building Roof Slabs at Elev. 140 ft.
  - Slab No. 5 (Areas J & K)
  - Slab No. 11 (Area GE)

Engineering Study Assumptions/ Methodologies – Structures

	Study	Licensing Basis
Vertical Input Motion	Dynamic amplification	Rigid, no amplification
Vertical DE/DDE Load Application	Response spectral analysis	Static
Damping Ratios (for vertical analyses)	<u>Containment</u> DE = 4% DDE = 7% <u>Auxiliary Building</u> DE = 4% DDE = 7%	<u>Containment</u> DE = 2% DDE = 5% <u>Auxiliary Building</u> DE = 5% DDE = 5%

Engineering Study Assumptions/ Methodologies – Structures (cont.)

	Study	Licensing Basis
Foundation Conditions	Fixed base (vertical)	Soil structure interaction (horizontal only)
Spatial Combination	SRSS combination of vertical and two horizontal	Absolute sum combination of vertical and one horizontal
Vertical Response Spectra Development	Per RG 1.122 33 Hz. cut-off 15% broadening	None
Frequency Cut-off	Frequency $\geq$ 33 Hz.	Frequency $\geq$ 20 Hz.

Engineering Study Results – Containment Structure

- Evaluated for the following loads
  (1) 1.05 Dead + 1.5 Pressure + Thermal
  (2) 1.05 Dead + 1.25 Pressure + Thermal + 1.25 DE
  (3) 1.05 Dead + 1.00 Pressure + Thermal + 1.00 DDE
  (4) 1.05 Dead + 1.00 Pressure + Thermal + 1.00 HE
- Interaction ratios (demand/capacity) for center of dome for critical structural components:

Component	Load Case	Design Basis	Study
Rebar	(1)	0.75	--
	(2)	0.68	0.68
	(3)	0.56	0.57
	(4)	0.53	--
Liner Plate	(1)	0.30	--
	(2)	0.26	0.27
	(3)	0.22	0.23
	(4)	0.23	--

Engineering Study Conclusion – Containment Structure

- The Design Basis evaluation demonstrated that the design is governed by Load Case (1) due to the large multiplier on the internal pressure
- Adding vertical amplification does not impact this conclusion

Engineering Study Results – Auxiliary Building Slab Nos. 5 & 11

- Evaluated for the following load cases:
  (1) Dead + Live + DE (Working Stress Design)
  (2) Dead + Live + DDE (Ultimate Strength Design)
  (3) Dead + Live + HE (Ultimate Strength Design)
- Load Case (1) governs

Engineering Study Results – Auxiliary Building Slab 5 & 11 (cont.)

- Interaction ratios (demand/capacity) and seismic margin factors for critical region of slab no. 5:

	Interaction Ratio		Seismic Margin Factor -
Load Component	Design Basis	Study	Study
Moment	0.92	0.93	2.8
Shear	0.92	0.93	2.7

- Interaction ratios and seismic margin factors for critical region of slab no. 11:

	Interaction Ratio		Seismic Margin Factor -
Load Component	Design Basis	Study	Study
Moment	0.89	0.90	3.2
Shear	0.93	0.94	2.2

Engineering Study Conclusion – Auxiliary Building Slab Nos. 5 & 11

- The Design Basis evaluation is governed by Load Case (1) due to the acceptance criteria based on working stress design and the dominance of dead and live loads
- The results of the Engineering Study indicate that the slabs satisfy DE code allowables when the amplification of vertical seismic motion is considered

Engineering Study Conclusion - Structures

- Containment Structure and Auxiliary Building slabs at elev. 140' satisfy DE/DDE code allowables when the amplification of vertical seismic motion is considered

Engineering Study Scope – Other Components

- Plant Vent
- HVAC Ducts and Supports
- Electrical Raceways and Supports

Engineering Study Assumptions/ Methodologies – Plant Vent

	Study	Licensing Basis
Vertical Input Motion	Dynamic amplification	Rigid, no amplification
Damping Ratios (for vertical analyses)	DE = 2% DDE = 4%	DE = 2% DDE = 4%
Spatial Combination	SRSS combination of vertical and two horizontal	Absolute sum combination of vertical and one horizontal
Frequency Cut-off	Frequency $\geq$ 33 Hz.	Frequency $\geq$ 20 Hz.

Engineering Study Results - Plant Vent

- Evaluated for the following load cases:
  (1) Dead + Live + Operating Pressure + DE (Working Stress Design)
  (2) Dead + Live + Accident Pressure + DDE (Plastic Design)
  (3) Dead + Live + Accident Pressure + HE (Plastic Design)

- Results:
  - The design basis evaluation of critical components (support frames and anchorage to Containment Structure) enveloped all load cases and compared them to working stress design allowables.
  - Study DE acceleration (0.48g) is less than HE (1.5g).

Engineering Study Conclusions - Plant Vent

The Engineering Study demonstrates that the Plant Vent satisfies DE/DDE code allowables when the amplification of vertical seismic motion is considered

Engineering Study Assumptions/ Methodologies – HVAC and Electrical Raceways

	Study	Licensing Basis
Vertical Input Motion	Dynamic amplification	Rigid, no amplification
Damping Ratios (for vertical analyses)	<u>HVAC</u> DDE = 4% <u>Electrical Raceways</u> DDE = 7%	<u>HVAC</u> DDE = 2% <u>Electrical Raceways</u> DDE = 7%
Spatial Combination	<u>HVAC</u> SRSS combination of vertical and two horiz. <u>Electrical Raceways</u> Same as Licensing Basis	<u>HVAC</u> Absolute sum comb. of vertical and one horiz. <u>Electrical Raceways</u> Absolute sum comb. of vertical and one horiz.
Frequency Cut-off	Frequency $\geq$ 33 Hz.	Frequency $\geq$ 20 Hz.

Engineering Study Results – HVAC and Electrical Raceways

- Engineering Study addressed raceways and HVAC duct supports
- Supports evaluated for following load cases:
  (1) Dead + DDE
  (2) Dead + HE
- Acceptance criteria is identical for both load cases
- DDE loads increase due to vertical amplification, but since Engineering Study uses same damping ratios for DDE as are used for HE, load case (2) governs

Engineering Study Conclusions - HVAC and Electrical Raceways

The Engineering Study demonstrates that HVAC and electrical raceways satisfy the licensing basis acceptance criteria when amplification of vertical seismic input motion is considered

Engineering Study to Confirm Adequate Margin – Overall Conclusions

- When vertical amplification is considered, the studied SSCs meet all acceptance criteria:
  - All equipment tested by shake-table is qualified
  - For equipment qualified by analysis, the vertical seismic component is not significant
  - Piping and supports meet DE/DDE code allowables
  - Containment structure and two auxiliary building slabs meet DE/DDE code allowables
  - Plant vent meets DE/DDE code allowables
  - HVAC and electrical raceways meet acceptance criteria

Conclusions

- Decision not to shut down was appropriate
  - San Simeon Earthquake ground motion was much less than OBE/DE
  - No damage to DCPP structures, systems and components
- San Simeon excursion above DE vertical response spectra at top of containment was to be expected
- DCPP DE licensing/design basis provides adequate margin for OBE function

Earthquakes Considered Post LTSP

Earthquake	*Magnitude*	*Style of Faulting*
1989 Loma Prieta, CA	7.1	Complex buried strike-slip/Oblique
1992 Landers, CA	7.3	Complex strike-slip
1994 Northridge, CA	6.8	Buried complex thrust
1995 Kobe, Japan	6.9	Complex strike-slip
1999 Kocaeli, Turkey	7.4	Simple strike-slip
1999 Duzce, Turkey	7.1	Simple strike-slip
1999 Chi-Chi, Taiwan	7.6	Complex reverse
1999 Hector Mine, CA	7.1	Complex strike-slip
2001 Kunlun, Tibet	8.1	Complex strike-slip/normal/reverse
2002 Denali, Alaska	7.9	Complex strike-slip/reverse/normal
2003 San Simeon, CA	6.5	Complex buried reverse

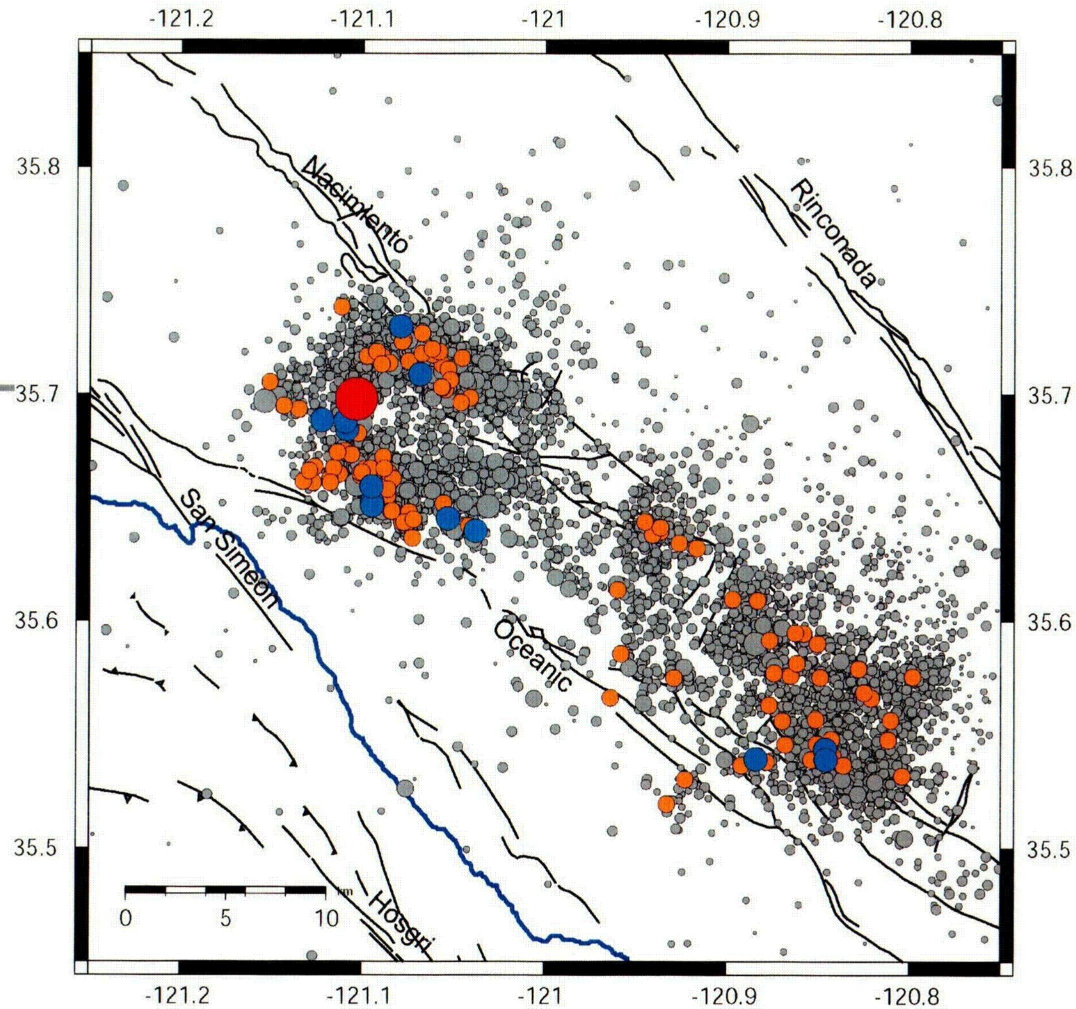
LTSP Source Characteristics and Ground Motion Attenuation

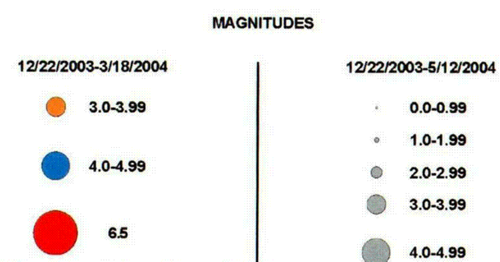
- Maximum magnitudes assigned to earthquake sources
- Source zone configurations and geometries
- Earthquake recurrence rates
- Probability of activity assigned to faults and source zones
- Appropriateness of attenuation relationships to estimate ground motions
- Considerations given to thrust faulting on Hosgri fault

Geosciences Summary

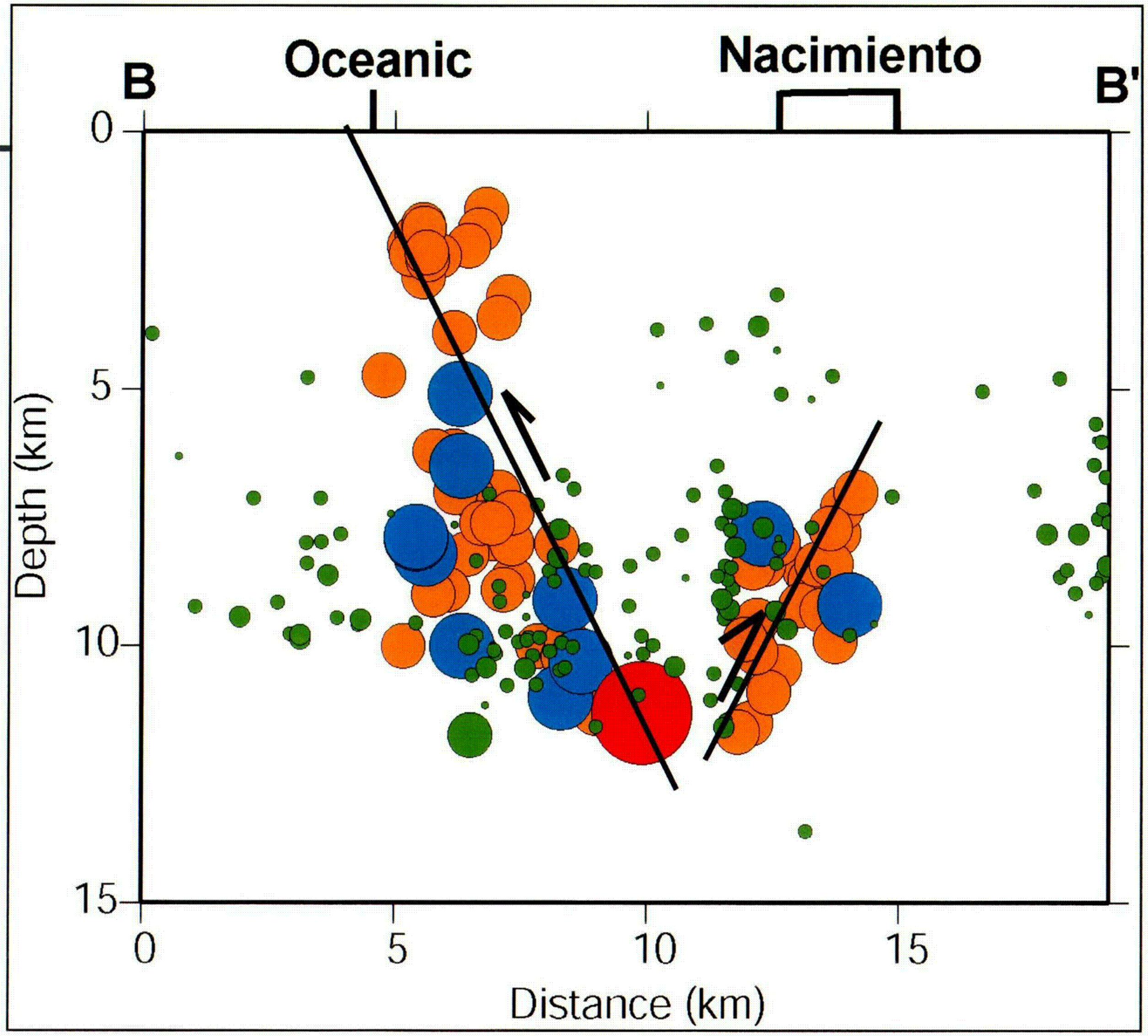
- Maximum magnitudes assigned to earthquake sources
  - Rupture Dimension of San Simeon: 35km x 14 km
  - M6.5 of San Simeon earthquake is smaller than the expected magnitude based on LTSP M(Length) and M(area) models for reverse faults (M6.8-M7.2)
  - No need to increase maximum magnitudes
- Source zone configurations and geometries
  - San Simeon earthquake hypocentral depth of 11-12 km is consistent with through-going high angle fault model used in LTSP.
  - No need to revise source geometries based on San Simeon earthquake
  - Additional work on depth distributions needed to reach consensus with USGS researchers

San Simeon Aftershocks





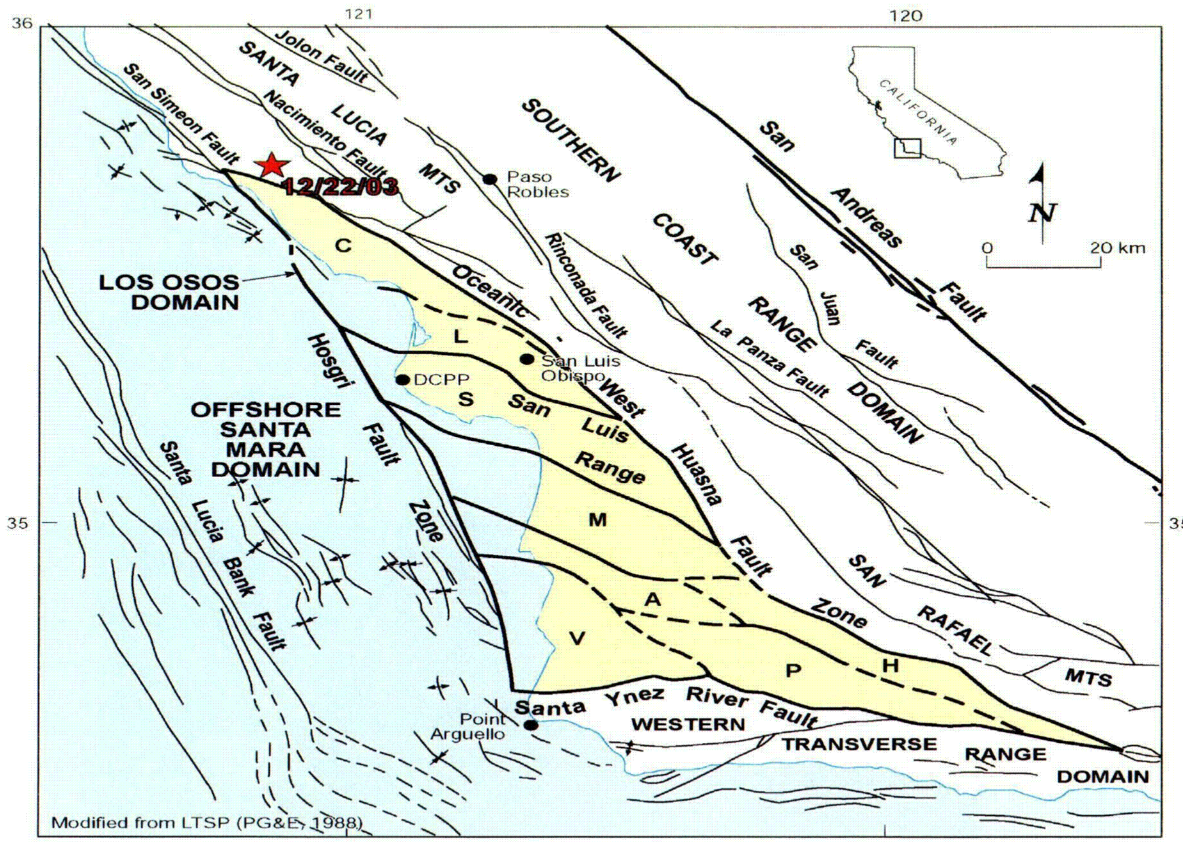
C05



B
Oceanic
Nacimiento
B'
0
5
10
15
Depth (km)
0
5
10
15
Distance (km)

Geosciences Summary

- Earthquake recurrence rates
  - Occurrence of single earthquake sequence does not have a significant effect on recurrence rates (for PSHA)
  - No revision to earthquake recurrence rates needed based on San Simeon earthquake
- Probability of activity assigned to faults and source zones
  - Oceanic fault considered active reverse fault in LTSP (and by CDMG)
  - Occurrence of San Simeon earthquake does not affect probability of activity assessments



(from PGE LTSP 1988, Fig 2-8)

San Simeon PG&E

From Jennings, 1994

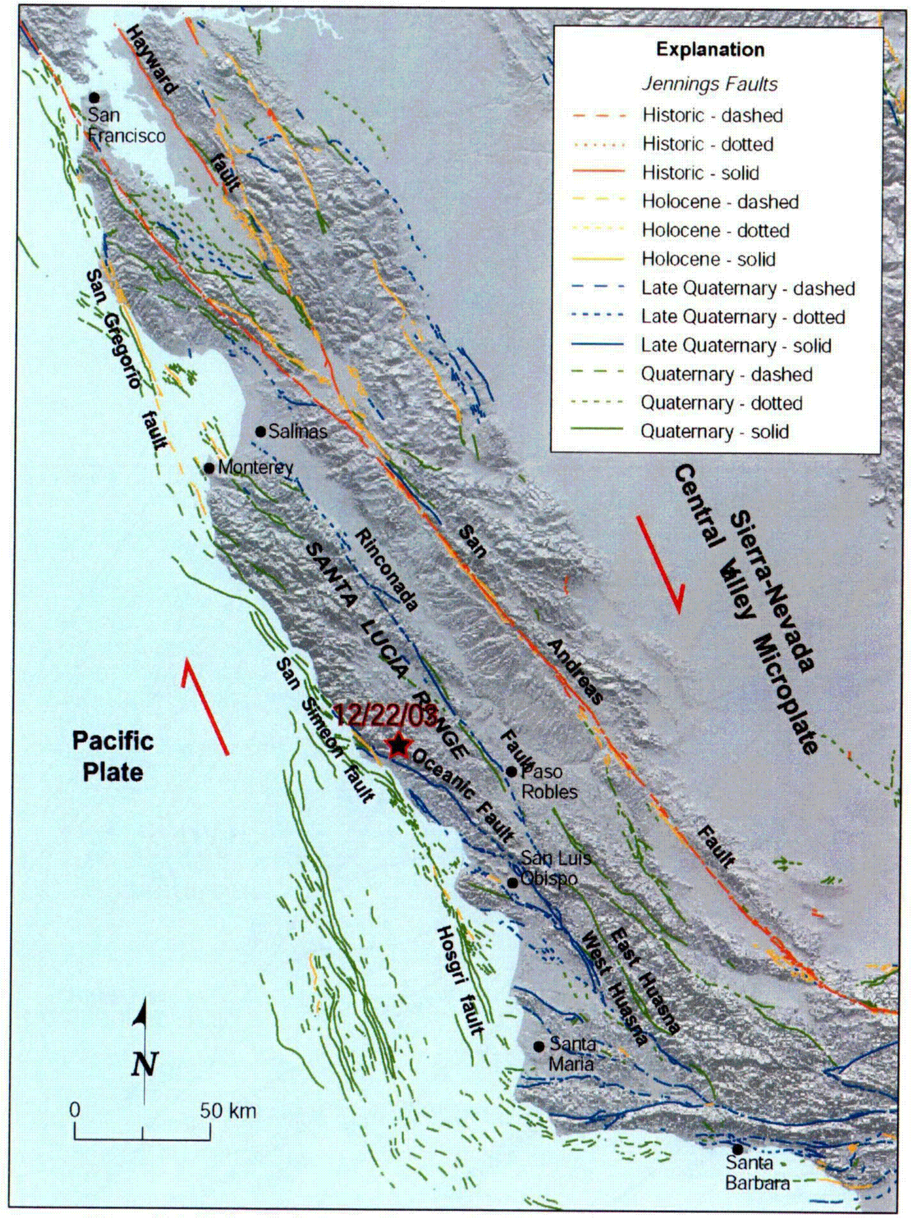
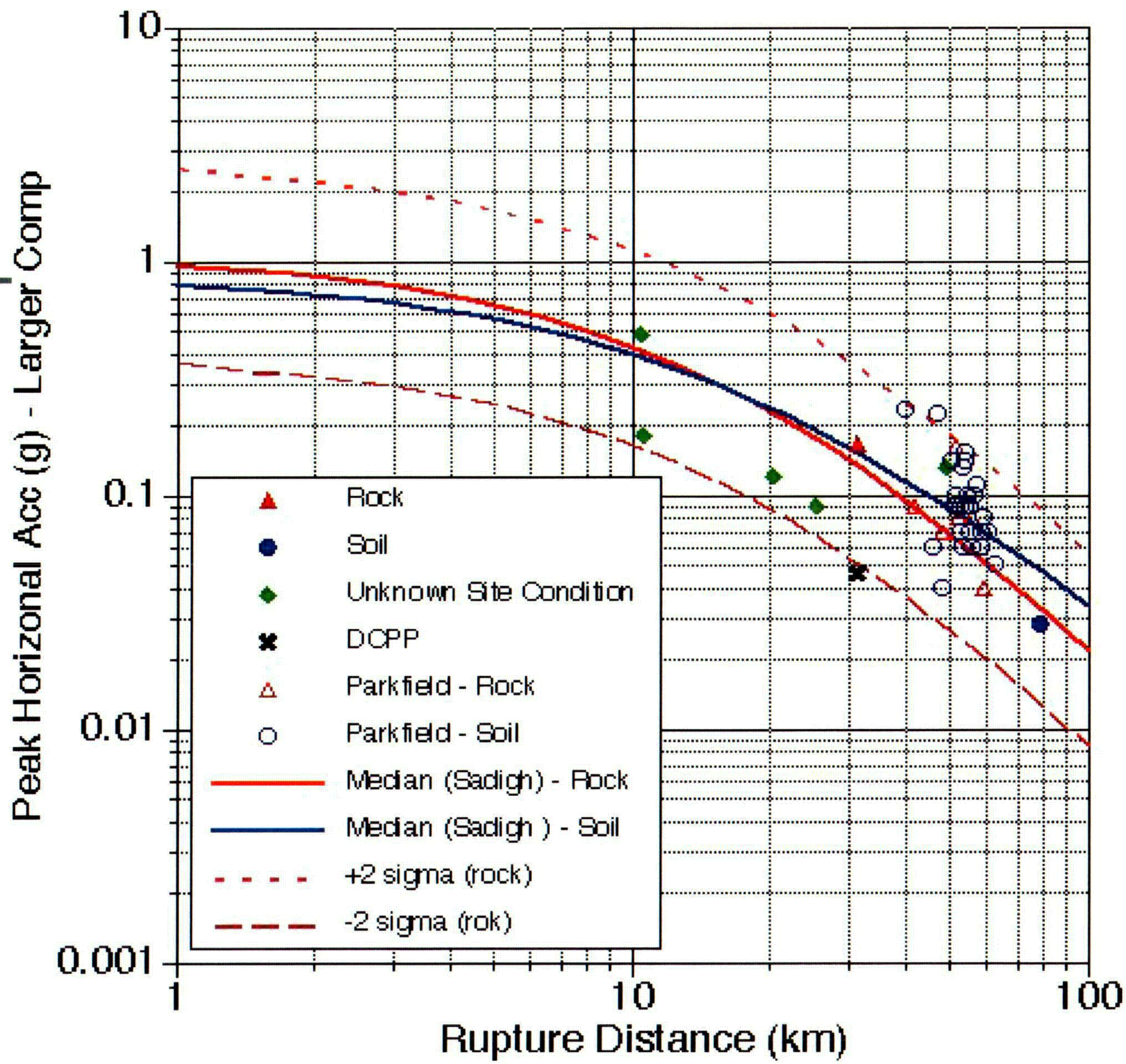


Figure 2-1. Active faults in south-central California (from Jennings, 1994).

Geosciences Summary

- Appropriateness of attenuation relationships to estimate ground motions
  - Free-field ground motions recorded at DCPP from the San Simeon earthquake were much smaller than expected
  - Lower ground motions may reflect effects of hard rock conditions at DCPP (as compared to generic "rock" used in ground motion models)
  - Ongoing NGA project is developing new attenuation relations that incorporates new strong motion data from recent large magnitude earthquakes



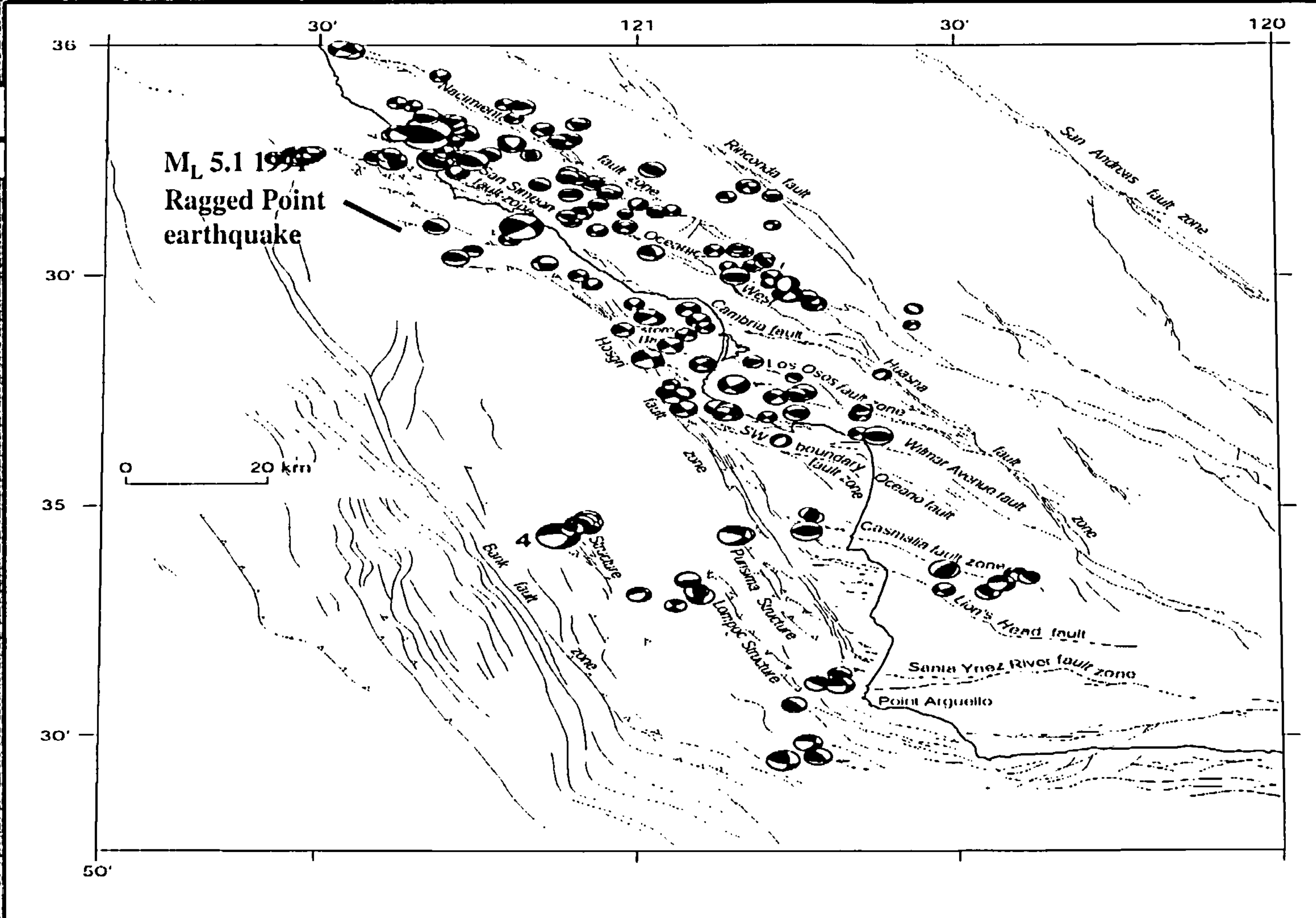
10
1
0.1
0.01
0.001
1
10
100
Peak Horizonal Acc (g) - Larger Comp
Rupture Distance (km)
Rock
Soil
Unknown Site Condition
DCPP
Parkfield - Rock
Parkfield - Soil
Median (Sadigh) - Rock
Median (Sadigh) - Soil
+2 sigma (rock)
-2 sigma (rok)

C09

Geosciences Summary

- Considerations given to thrust faulting on Hosgri fault
  - LTSP considered alternative style-of-faulting for Hosgri
    - 65% strike-slip
    - 30% reverse/oblique
    - 5% reverse
    - (NRC combined reverse/oblique and reverse)
  - Focal mechanisms from recent seismicity show mainly strike-slip mechanisms along the Hosgri fault
  - No basis for increasing weight of reverse style-of-faulting on the Hosgri

Focal mechanisms – 1987-1997



 From McLaren and Savage, 2001

Future Actions

- Geoscience Reports
  - LTSP Actions
  - Supplemental Report
  - Final Report